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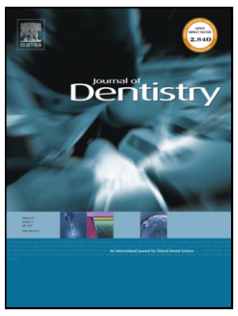

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The effect of scanned area on the accuracy and time of anterior single implant scans: an in vitro study

Short Title: Accuracy of digital single anterior implant scans

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Abstract

Objectives: To investigate the effect of scanned area on the accuracy and scan time of intraoral scans of an anterior implant.

Materials and Methods: Three operators experienced in intraoral scanning (at least 2-year experience) performed partial and complete-arch scans ($n=10$) of a dentate resin model with an implant at left central incisor site by using an intraoral scanner (Trios3; 3Shape, Copenhagen, Denmark). Each partial- or complete-arch scan was superimposed to a reference scan from a laboratory scanner (Ceramill Map 600; Amann Girrbach AG). Mean distance (selected 7 points) and angular (mesiodistal and buccolingual) scanbody deviations in test scans (trueness) and their variance (precision) were calculated. Linear-regressions (trueness), two-sided F-tests with a Bonferroni correction (precision), and multiple linear regressions (scan time), with the operator as a covariate were applied ($\alpha=.05$).

Results: Interactions were found between the scanned area and the operator for their effect on trueness of all points and angles, except for point 6 at implant-abutment connection in mesiodistal plane ($p<.05$). No significant difference was found between the precision of partial and complete-arch scans for all operators ($p>.05$). Partial-arch scan times were significantly shorter, overall, and for each operator ($p<.001$). No significant effect of scan time was found on the trueness of partial- and complete-arch scans ($p>.05$).

Conclusions: Partial and complete-arch scans of anterior single implants with an intraoral scanner resulted in similar accuracies, and were not influenced by the operator or the scan time. Scan times of partial-arch scans were significantly shorter.

Clinical Significance: Partial-arch scans can be used for the fabrication of monolithic anterior single implant crowns because the scans can be completed in shorter times without compromising the accuracy.

Keywords: accuracy, intraoral scan, implant scan, implant crown, operator influence

INTRODUCTION

Intraoral scans have improved in terms of accuracy in recent years [1], and they can be used for the fabrication of diagnostic casts [2], to fabricate tooth- or implant-supported partial dentures [3], and also complete dentures [4,5]. Although their improvement has been reported, various factors, which affect the accuracy of scans have also been identified [6] such as intraoral scanner and scanner software, scan strategy, scanbody design, light conditions, experience of clinician in scanning, surface of the scanned area, extent of the edentulous scanned area, and the angulation between the scanned implants [3,4,6–11]. There is agreement on the effect of some of these factors. However, there are contradictory statements on the effect of the size of scanned area and the experience of clinician in scanning on the accuracy of implant scans [3,12].

Intraoral scans are commonly performed for the fabrication of tooth- or implant-supported single crowns as there is agreement on the adequacy of accuracy of scans of single units [7,13]. However, when the size of the scanned area is considered, there are different recommendations on how to best perform the scan to achieve the highest possible accuracy [14]. The current consensus for digital scans of posterior segments is to perform only quadrant scans when possible, as quadrant scans were found more accurate than complete-arch scans [12,15]. The primary reason for the greater inaccuracy for complete-arch scans was reported to be the difficulty with stitching individual images, which is performed by the software [16]. Accordingly, higher scan accuracy can be expected in the quadrant that is scanned first compared with the second [15]. A complete digital workflow, including quadrant scanning, has been demonstrated to be possible for the fabrication of screw-retained monolithic posterior single implant crowns [17,18]. In addition to the higher accuracy, quadrant scanning is time-saving compared with the complete-arch scans, which can be clinically important [19]. In light of results of published studies, quadrant scans can be advantageous for the fabrication of a posterior single implant crown. However, there are conflicting reports regarding the accuracy of scans when different regions are scanned. A recent in vitro study demonstrated higher inaccuracies with the scans of anterior region compared with posterior [1]. Whereas, another study demonstrated higher inaccuracies with the scans of posterior teeth compared with those in the anterior [20]. Restricting the scan to the anterior region may be problematic because of possible image stitching problems and also because of the absence of posterior stops. Complete-arch scans require more time to scan and the complexity of the scans increase as the area to be accurately captured increases. To the authors' knowledge, the accuracy of anterior single implant scans depending on the scanned area is not extensively studied with no agreement in the literature.

Therefore, the aim of the present study was to investigate the effect of scanned area (partial or complete-arch) on the accuracy (trueness and precision) of single implant scans at central incisor position by three different operators with similar experience in intraoral scanning. In addition, the influence of scanned area and operator on scan time, and the effect of scan time on trueness of scans were aimed to be analyzed. The null hypothesis was that the scanned area and the operator would not affect the accuracy of implant scans. Also, the null hypotheses that the scanned area would not affect the scan time, and the scan time would not affect the scan trueness were tested.

MATERIALS and METHODS

Scan-model and data acquisition

A printed partially edentulous maxillary model (Form 2; Formlabs Inc, Somerville, MA, USA) with an implant (4.0×11 mm) (Proactive Straight Implant; Neoss, Woodland Hills, CA, USA) at maxillary left central incisor was used in the present study (Fig. 1). An intraoral scanbody (Intra-Oral Scanbody, Neoss, Woodland Hills, CA, USA) was tightened to 10 Ncm by using a digital torque meter. The model was scanned by using a laboratory scanner (Ceramill Map 600; Amann Girrbach AG, Koblach, Austria) to obtain a reference scan. Three operators who have similar digital scan experience (at least 10 pilot scans and 2-year experience with scanning) with the intraoral scanner (Trios 3; 3Shape, Copenhagen, Denmark) scanned the same model including all teeth and the scanbody (complete-arch scan)(n=10). The operators also performed partial-arch scans, from the distal of right canine to the distal of left 2nd molar (n=10), and the scanbody. The order to perform all scans was randomized by using a software program (Excel; Microsoft, Redmond, WA, USA). All operators followed the same scan path for all scans, which was recommended by the manufacturer of the scanner; the scans started on the occlusal of left second molars, continued on occlusals/incisals of remaining teeth in each scan area group followed by their linguals and buccals. Complete- and partial-arch scans were always alternated to avoid a training effect for a specific type of scanning as much as possible. The scan times were recorded, and the scan files were converted to standard tessellation language (STL) format.

Evaluation of accuracy

The scans from the intraoral scanner were exported to a 3-dimensional metrology software (GOM GmbH; Braunschweig, Germany–version 2018 Hotfix 7, Rev. 120738, Build 2019-08-23) for superimpositions with the reference scan (Fig. 2). On the reference scan, 2 planes (buccopalatal (x plane) and mesio-distal (y plane)) were created crossing the center of the scanbody. Seven points were selected at different locations of the scanbody. On x plane: 1 - implant-abutment-connection, 2- most buccal-coronal, 3 - middle of buccal plane, 4 - middle of palatal plane, 5 – most palatal coronal point (Fig. 3A); and on y plane: 6 – implant-abutment connection and 7 – most mesial coronal point (Fig. 3B). The scanned models were initially aligned by using the software's prealignment feature. Then, for partial-arch scan alignment, the area including teeth between left lateral and second molar, and for complete-arch alignment, all teeth except for the scanbody site were selected for further alignment by using the "local best fit" alignment tool. Only the left quadrant was used for the superimposition of the partial-arch scans, excluding the scanbody. The coordinates for predefined points (1-7) were then added, and the program's algorithm generated the 3-dimensional (3D) variation between the points on the reference and the model scans. Using the points identified in the superimposed scans, for buccolingual angle measurements (Angle 1), lines were drawn in both scans between points 1 and 2, and for mesiodistal angle, lines were drawn between 6 and 7. Point 1 and 6 were the points at implant scanbody connection on the reference scan. The angulation between the line from point 1 and point 2 in reference scan and the line from point 1 in reference scan and point 2 in test scan was the angular discrepancy of the scanbody in buccolingual direction. The angulation between the line from point 6 and point 7 in reference scan and the line from point 6 in reference scan and point 7 in test scan was the angular discrepancy of the scanbody in mesio-distal direction (Angle 2). The data generated (3D distance deviations at seven points and buccopalatal and mesiodistal angles) were tabulated (Excel, Microsoft Corp.) for statistical analysis.

Statistical analysis

Linear regression was used to explore the effect of scannned area and operator on each measurement of the scan trueness. The difference between scan time of partial and complete scan was tested by simple linear regression for each operator separately and all three operators together. To compare the precision of partial and complete scans, two-sided F-tests were implemented to compare the variance of scan deviations. The F-statistic, which indicates the ratio of partial versus complete scan precision, was reported for each deviation measurement and operator separately. The F-test p-values were Bonferroni-corrected accounting for the multiple comparison of 9 deviation measurements within each operator. The effect of scan time on the trueness for each scanned area was also explored separately by multiple linear regression models, where the operator was included as a covariate in addition to scan time to adjusting for its potential confounding effect. The coefficients of scan time and Bonferroni-corrected p-values were reported (alpha=.05). The Bonferroni correction was for the 9 deviation measurements within each scanned area.

RESULTS

When the effect of operator and area on scan trueness was considered, significant interactions were found between the region and the operator at all points and angles except for point 6 ($p<.05$). The overall mean trueness (independent of the operator) ranged from 29 ± 11 μm (Point 5) to 319 ± 30 μm (Point 6). The effect of operator on trueness differed in partial and complete-arch scans and the effect of region on trueness differed by the operator. When the results were further resolved, the deviations were smaller for complete-arch scans compared with partial-arch scans for all operators at point 6 ($p=.027$) (Fig. 4). At point 6, deviations in scans of operator 3 were significantly smaller than the other operators ($p<.001$) (Fig. 3). When the precision of scans was considered, no significant difference was found between partial and complete-arch scans for each operator at any measurement point or angle ($p>.05$) (Figs. 4 and 5).

When the effect of region on scan time was considered, partial-arch scan times were significantly shorter than complete-arch scan times, overall and also for each operator ($p<.001$) (Fig. 6). The overall mean difference in scan time between partial- and complete-arch scans was 26 ± 7.7 seconds. When the effect of scan time on trueness was considered, no significant correlation was found between the scan time and trueness for partial and complete-arch scans ($p>.05$).

DISCUSSION

The null hypothesis that the scanned area and the operator would not affect the trueness of scans was rejected as complete-arch scans had higher trueness at point 6, and the scans of operator 3 had higher trueness compared with those of other operators also at point 6. The null hypothesis that scanned area would not affect the scan time was rejected as the scan time was shorter with partial-arch scans. The null hypothesis that the scan time would not affect the trueness was accepted as no significant effect of scan time was found on trueness.

The results for the first null hypothesis should be interpreted carefully. Even though the null hypothesis was rejected, the effect of region and operator was found significant at only one point (6) out of 7 points used. No differences between partial and complete-arch scans for the remainder of the evaluated points and angles, neither in terms of trueness nor in terms of precision, were demonstrated. It may be interpreted that there was no clear evidence to state that partial or complete-arch scans were superior to each other in terms of accuracy (trueness and precision) at points and angles the interaction was detected. At point 6, the scans of operator 3 showed significantly higher trueness compared to the other operators. No further differences, neither in terms of trueness nor precision, for any of the operators were demonstrated.

Point 6 is the interproximal point at the implant-scanbody connection. Acquiring this point with an intraoral scanner that relies on direct line of sight may be difficult because of this point's closeness to mucosa (slightly submucosal) and its interproximal position [21,22]. The significant difference at point 6 may be due to the difficulty in accessing this point when scanning rather than an advantage of the complete-arch scan. Although not statistically analyzed, the fact that deviations at point 6 were larger compared with those at other points increases the probability that the difficulty in accessibility played a greater role than the extent of the scanned area. The clinical relevance of higher trueness in complete-arch scans at point 6 can be expected to be small, as point 6 was not a part of scanbody's scan area, which represents the most important part of a scanbody to accurately record the implant position [10]. Accordingly, the deviations at point 6 may have a minor influence on the recorded implant position, which should be further studied fabricating crowns to evaluate their fit on the implant.

When considering the results in detail, trueness at specific points (1 to 7) and angles (1 or 2) varied within and between operators, and scanned area did not demonstrate a clear trend for superiority for any operator's scan and overall. The precision was similar between partial- and complete-arch scans for all operators. Accordingly, no clear trend was observed for superiority of accuracy between partial- and complete arch scans for any of the operators. Similarly, operators' effect on scan accuracy was similar, overall. Accordingly, with the intraoral scanner used, the accuracy of partial and complete-arch scans of three operators with similar experience was similar. A previous study reported that the error in scans was larger when the size of the scanned area and the distance from the scan origin increased [23]. However, the intraoral scanner used in the present study performed best in above mentioned study [23]. Also, the distance from the scan origin to the scanbody in partial- and complete arch scans was identical, which may be the reason for similar deviations found in the present study between partial- and complete-arch scans.

Different than previous studies, which focused on the accuracy of partial and complete-arch scans, in the present study, the analysis of accuracy was done specifically on a scanbody. Other studies rather evaluated the overall mean deviation instead of focusing on specific sites [1,15]. Furthermore, they demonstrated higher inaccuracies in the quadrant that was scanned later, which was not evaluated in the present study [15].

In previous studies, in general, the scans of inexperienced and experienced operators were compared demonstrating higher accuracy mostly for the scans of experienced operators when older versions of intraoral scanners were used [24–26]. However, when current intraoral scanners were used or operators experienced in intraoral scanning did the scans, no differences were demonstrated confirming the results of the present study [25,26]. The effect of operator's experience in scanning on the accuracy of anterior single implant scans should be further tested.

In the present study, the scan time for partial-arch scans was significantly shorter for all operators, pooled and analyzed separately. Similarly, a previous study [27] demonstrated that trueness and precision were highly correlated with the complete-arch scan times. [27] Because the accuracy of partial and complete-arch scans was not found different in the present study, partial-arch scans may be recommended for the fabrication of an anterior monolithic single implant crown due to favorable time-efficiency without compromising the accuracy.

Accuracy consist of trueness and precision. Trueness is the closeness of the mean of a set of measurement results to the actual (true) value. Precision, which is the closeness of agreement between measured values obtained by replicate measurements on the same object under specified conditions [29], was analyzed by using the variance in scan deviations. For trueness measurements, commonly used techniques considered the total deviation of all points in a point cloud from a reference data set or focusing on a specific region of interest within a point cloud [1]. Evaluation of total deviation is mainly used to compare the accuracy of different intraoral scanners or when analyzing complete-arch scans [28–31]. However, when an intraoral scan is to be used for the fabrication of dental prostheses, the points that directly influence the accuracy of fit of the prosthesis are of more interest. The area of interest for tooth-supported reconstructions would be the abutment and the adjacent teeth. Whereas, it would be the scanbody for implant-supported reconstructions. When focusing on the scanbody to evaluate the deviation of scans (trueness), it is possible to use all points on the scanbody or only the selected points and/or angles that are of specific interest. The advantage of using all points in the area of interest is that all available information can be used for comparisons. However, this technique can result in an underestimation of the deviation when large smooth areas, which play a minor role in the accuracy of prosthesis to be fabricated, are accurately superimposed. This situation would reduce the potential error in smaller but critical areas [22]. Accordingly, in the present study, specific points on the scanbody were used to analyze the deviations. The mean distance deviation at most of the evaluated points ranged between 40 and 100 µm. Previous studies, which evaluated the trueness of single implant intraoral scans reported similar deviations with small differences compared with the present study results when the same intraoral scanner was used [26,29]. The small difference found in results of different studies may be attributed to the method of evaluation, since the trueness values in mentioned studies consist of a large number of analyzed points even outside of the area of interest, which can lead to an underestimation of the deviation. Difference in operators in studies may have also led to differences in results. The angular deviations were mostly smaller than 0.5 degrees in buccopalatal and less than 0.75 degrees in mesiodistal direction regardless of the scan being partial or complete-arch. No studies focusing on angular deviations of single implant scans could be identified. A systematic review reported angular deviations of up to 1.6° in previous studies, and up to 0.3° in more recent studies for multiple implant intraoral scans [32].

In the present study, only one intraoral scanner was used and different results may be obtained with different scanners. However, the utilized scanner is commonly used and the addition of previously missing information to the existing literature through the findings of the present study can be considered valuable [28,34,35,36]. No sample size calculation to show the minimum number of scans to demonstrate a significant difference between the two experimental groups was performed. However, the number of scans used is higher than the number in comparable studies on posterior single implant crowns, where statistically significant differences were detected [29,31]. In addition, tight confidence intervals, and the fact that significant differences were detected for trueness and scan time in the present study are the indicators of the power of the sample size and the design. Although the reference data set was not created by a coordinate measuring machine or an industrial high-precision scanner, the use of laboratory scanner scans as a reference data set has also been recommended due to their accuracy, which is 4 microns as specified by the manufacturer of the scanner used in the present study [30,37–39]. Nevertheless, the use of a laboratory scanner to generate the reference scan dataset is a limitation of the present study. Future studies should be performed by using an industrial high-accuracy scanner to obtain an optimum reference dataset. In addition, the fact that a printed model was used can be considered as a limitation, because printed resin may be prone to dimensional changes over time [40]. Materials with high dimensional stability should be used to generate models when designing studies where scan superimpositions are planned in order to minimize dimensional stability sourced errors. The findings of the present study are limited to the implant system and its components tested and different results may be obtained with different implant systems. Scanbody material and shape may affect the accuracy and scan time, and these effects should be further tested [10,41].

CONCLUSIONS

The accuracy of partial- and complete-arch scans was similar when operators with similar experience in scanning performed the scans. Considering the shorter scan times and comparable accuracy, partial-arch scans can be used to scan anterior implants when tested scanbody and scanner were used.

Author contributions

Burak Yilmaz: Conceptualization, Data curation, Formal analysis; Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Drafting initial manuscript, reviewing and confirming final version

Vinicius Rizzo-Marques Investigation, Methodology, Validation, Visualization, Reviewing and confirming final version

Xiaohan Guo Data curation, Formal analysis, Reviewing and confirming final version

Diogo Gouveia Data curation; Formal analysis; Methodology; Reviewing and confirming final version

Samir Abou-Ayash Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Drafting initial manuscript, reviewing and confirming final version

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

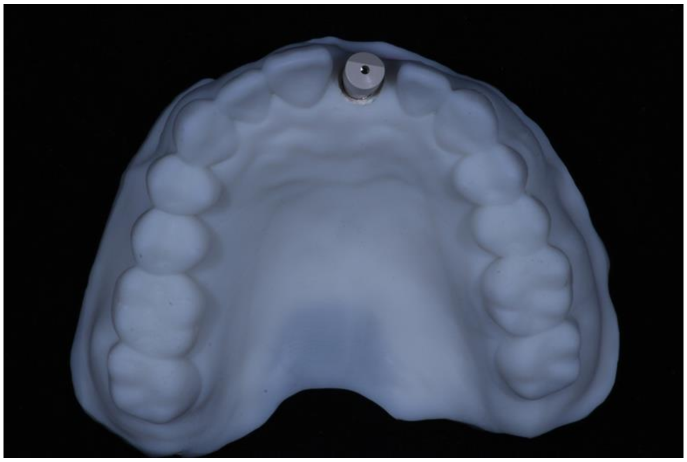


Fig. 1 **Study Model:** Occlusal view of the study model with a scanbody in the maxillary left central incisor position

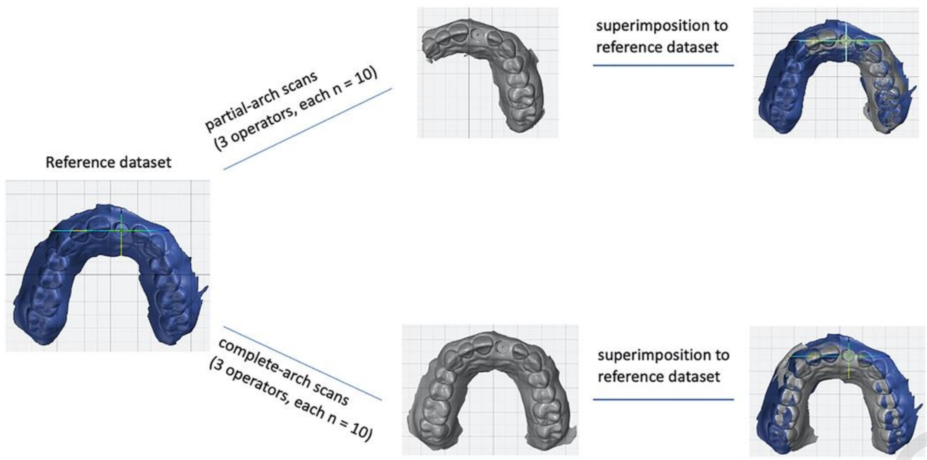
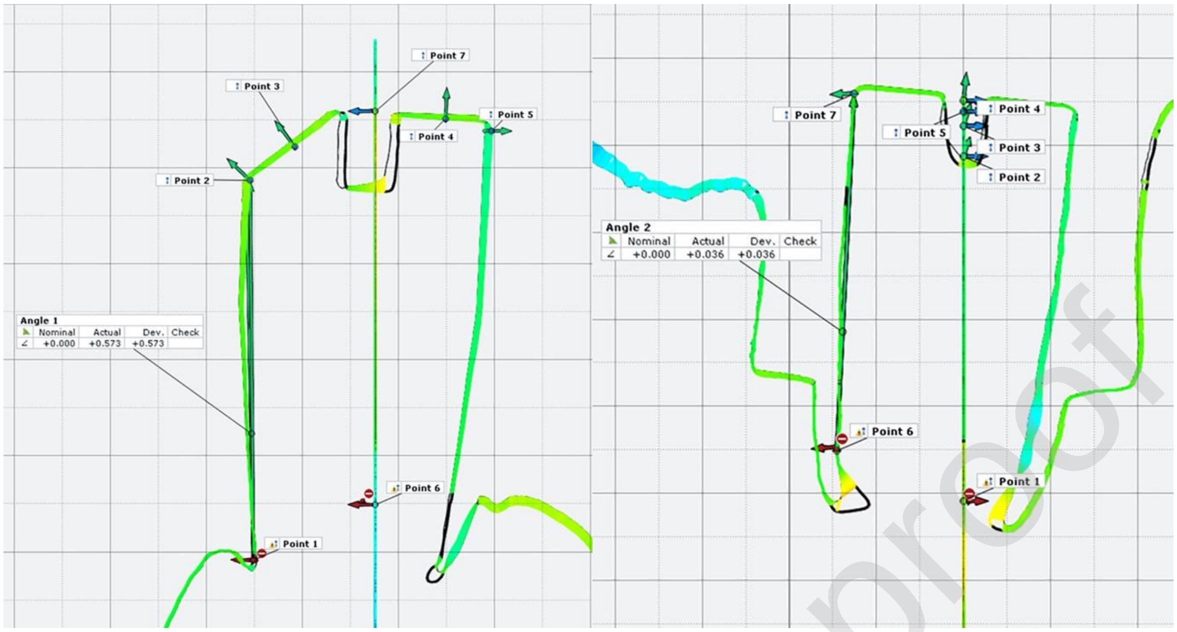


Fig. 2 **Study procedures:** Overview of the study procedures



Figs. 3 A and B **Investigated points and lines:** Points and lines that were used to measure distance and angular deviations (A) in the buccopalatal plane, and (B) mesiodistal plane

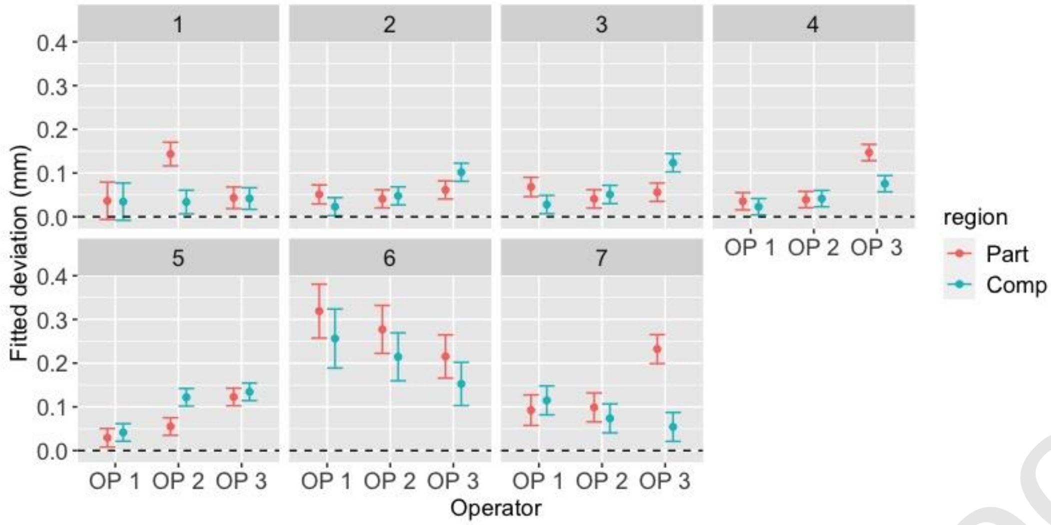


Fig. 4 **Distance Deviations:** Mean distance deviations and 95% confidence limits at selected points for each operator (OP)

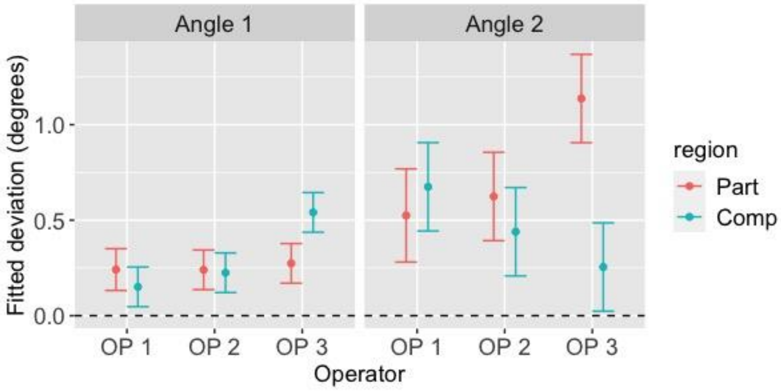


Fig. 5 **Angular deviations:** Mean angular deviations and 95% confidence limits in buccopalatal (Angle 1) and mesiodistal (Angle 2) directions for each operator (OP)

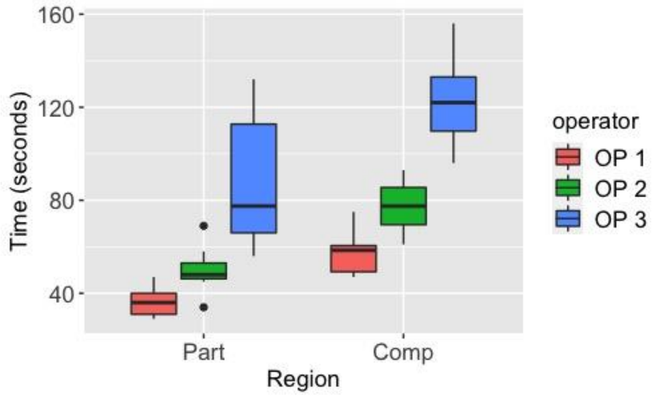


Fig. 6 **Scan time:** Box plot of partial (Part)- and complete (Comp)-arch scan time data for each operator (OP)